Variations of Microclimatic Conditions in Residential Neighbourhoods in Ho Chi Minh City

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ABSTRACT: The 5-year cycle of residential planning in Ho Chi Minh City (HCMC) has underestimated population growth since 1991. This has resulted in the disruptive and uncontrolled expansion of settlement across the city. The outcome is a complicated mix of new spontaneous dwelling areas in the city featuring a number of distinct urban morphologies. Some previous studies have shown impacts of such urban morphologies on the comfort levels in outdoor environments. The paper examines the correlation of microclimatic conditions and constituents that create the urban spatial form of residential neighbourhoods in HCMC. A total of seven dwelling urban patterns were studied. Field measurements of physical variables were conducted in summer 2017 whilst the meteorological data were recorded. Furthermore, in studies of two urban types, the microclimatic characteristics were found to vary under different urban contexts. During warm months, the outdoor thermal conditions for pedestrians were found to have average air temperatures between 32-34°C; a range of wind flow at the occupied level from 0.1-0.9m/s, and average humidity level of 57-60% over all types surveyed. The occupants' delight in outdoor comfort was found in formally planned dwelling blocks; meanwhile, the compact neighbourhoods were characterised by cooler temperatures but poor airflows and daylighting.
KEYWORDS: Urban structure, microclimate, comfort, residential buildings, Ho Chi Minh City

1. INTRODUCTION

Since the initiation of the 'Doi Moi' economic renovation in 1986, many reforms have occurred across Vietnam, in which HCMC has played the leading role [1]. The economic changes are linked to an explosion of population and urbanisation. The census 2015 concluded the total population of HCMC to be nearly 9m people; this figure is almost 1.8 times higher than in 1999. Over 90% of citizens live in urban areas [2,3]. The population growth is linked to a massive urban expansion and increase of housing demand from both local people and immigrants. The city area covered by hard construction surfaces increased by 20% between 1989 and 2006 and is associated with an increase in average surface temperature of 4°C in urban areas [4].

The exacerbation of urbanisation and population results in chaotic urban development without clear management of long-term planning and priorities in HCMC. The increasing urban heat island (UHI) impact caused by land use and city configuration along with climate change have negative influences on comfort conditions, health, and energy use of buildings [5]. Variations of urban geometries contribute to the differences of microclimate and outdoor comfort for occupants which can be beneficial. Many authors pointed out this relationship at different urban scales: building-to-building, urban blocks, and city scale [6,7].

Using a database for systematical classification of urban structure types in HCMC [8], this paper analyses the variations of urban patterns related to residential buildings through their urban constituents. It then identifies the variation in environmental performance according to the different urban types. Finally, the effects of urban morphology on microclimate are determined by application of a combination of three methods (consisting of mapping, field measurements, and simulation).

The study goes on to propose appropriate recommendations for the urban design of residences to improve outdoor thermal comfort that can lead to greater satisfaction with indoor ambient conditions and consequent reductions in energy demand.

2. AREA OF STUDY

HCMC is the second largest city in Vietnam and is located in the South-Central part of the country. The city experiences a climate of high air temperature, high humidity, and heavy rainfall throughout the year. The mean annual temperature is 28°C; however, over summer the extreme temperature peaks at 40°C. The average monthly relative humidity ranges from 70% to 85% [9]. Two prevailing winds through the city are west and southwest monsoon winds in the rainy season and the north and northeast monsoon winds in the sunny season. Furthermore, the trade wind from south and southeast also operates from March to May.

The total of city area of 2093 km² is occupied by four regions: core-centre, former inner, new inner, and suburban. The city projections to 2025 expect a rise in population to 13.9m, an expansion to 750km² of built-up area, urbanisation of new inner and suburban districts and a decline in population in the centre [10]. Since 2015, over 300 residential projects have been developed across the city; mainly in new districts and peripheral areas. Impacts from expanding residential neighbourhoods as well as global warming have accelerated the urban environment's vulnerability. The microclimate has changed with greater variability between neighbourhoods and increasing risks for comfort and air quality experienced by occupants in HCMC. The city's mean temperature has risen by 0.9-1.2°C since 1958 [11]. The climate changes and man-made modification result in the unsatisfactory microclimatic conditions in and around buildings, and trends for increased energy use by households.

3. STUDY ON URBAN STRUCTURE TYPES

Between 2010 and 2014, a research group from the University of Cottbus, Germany carried out a project on the adaptation of HCMC to climate change. One valuable outcome was the categorisation of the urban structures related to building types, urban elements, and their constitution for both fully planned and informally designed areas. By using a tool of Land-use Map 2010 at a scale of 1:25,000 combined with fieldwork, a total of 82 city structure typologies were identified covering 16,292 blocks. In this, a subset of 5 major types was classified: residential, public & special use, industrial & commercial, green spaces, and traffic system & water networks.

Table 1: Summary of urban structure types of 'shophouses' (source: Downes & Storch, 2014)

Type	'Shophouse' category	No of blocks	Build. ratio	Surface area (ha)
1	Regular new community	62	60	392
2	Regular new	100	70	450
3	Regular + narrow street	592	75	2,063
4	Irregular high density	425	78	1,602
5	Irregular + yards	794	57	4,444
6	Shophouse irregular & regular	23	69	350
7	Regular + yards	153	44	2,020
8	Irregular clustered	741	30	5,490
9	Irregular scattered	815	28	6,990
10	Irregular +large gardens	2,342	5	17,133
11	Irregular temporary			85
12	Shophouse + industry	222	74	1,292

Settlement structures were assigned to 6717 blocks including 12 patterns and with 6436 blocks categorised as urban low-rise dwellings, which occupied 20.5% of the total HCMC surface area (Table 1) [8]. The density of all dwelling urban structures differs over the city. The morphologies of residential blocks are determined by land use, coverage ratio, road patterns, housing archetypes, building stories, green areas, spatial planning, and population density. For this paper, seven urban geometries highlighted in Table 1 were studied considering physical characteristics, climate, and impacts of urban components on the environment.

4. RESEARCH METHODS

4.1 Collection of residential urban types for analysis

All seven categories which provide a good selection of commonly dwelling urban structures were visited and outdoor environmental parameters were measured. The proportions of the investigated urban types are shown in Figure 1, in which, Type 3 & 4 are the most dominant. Each type is characterised by a distinct spatial morphology; however, because of some similar constituents of some urban typologies, four groups of urban types were identified: Group 1 (Type 01 & 02), Group 2 (Type 3), Group 3 (Type 04, 05 & 06), and finally, Group 4 (Type 7) (Figure 2).

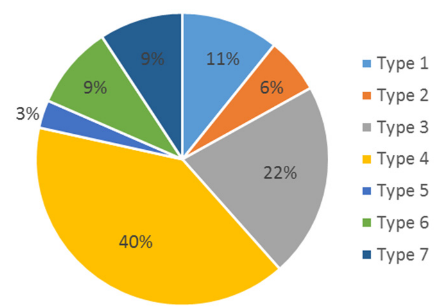

Figure 1: Sector of urban housing types in the research

Group 1 was characterised by terraced housing archetypes located perpendicular to main streets in a back-to-back pattern, and with communal spaces within each residential block. The distribution of Group 1 is high in new and peripheral districts of HCMC. Group 2 has a high density of occupancy found in the 2060ha of the inner-core and new inner areas of the city. The spatial structure of Group 2 has the regular development of low and high shophouses facing to narrow streets/alleys. The spaces within buildings are usually narrow and open to the main streets. Group 3 includes three urban types; the major feature of this group is an irregular and non-homogeneous high-density pattern of dwellings with narrow streets or alleys. The buildings are located along the outer edges of the main streets. The houses' architecture varies with no single archetype. Group 4 is generally found in the new inner and suburban neighbourhoods of HCMC. This group's morphology is characterised by a less dense structure and regular arrangement of houses. The housing types found in this group include new and rudimentary houses of one to three stories along main streets. Within buildings, many unplanned green spaces can be found.

Figure 2: Five urban structure types for studying (1: Type 1, 2: Type 2, 3: Type 3, 4: Type 4+5+6, and 7: Type 7)

4.2 Research techniques

Three techniques of analysis were used: mapping, field measurements and simulation. Mapping is a tool to understand the urban form and building footprints of the urban blocks through satellite photos and negative drawings. The microclimate of the urban blocks was estimated from simulation software. For the field study, 59 locations covering seven urban typologies of terraced houses around HCMC were visited in April and May 2017. The climate in these two months is the most rigorous because of heat and lower precipitation. For each dwelling block, a house was selected with measurement of indoor and outdoor air temperature, relative humidity (RH), and airspeed. Date and time of measurement, as well as, sky condition were also recorded. The measurements were carried out from 9:00 am until 17:00 pm over two months. The outdoor environmental parameters were collected from manual instruments at the level of pedestrians and were read after 3 minutes of calibration. Air velocity was averaged by a number of measurements over 3 minutes. Along with the field measurements, the meteorological data of city weather station were also recorded.

For simulation, the software of ENVI-Met was used to estimate the thermal conditions in terms of air temperature and air movement for the months of March, June, September and December; and from 9:00 am to 15:00 pm. The simulation was processed for sample areas defined by zones of 100mx100m (Figure 7).

5. RESULTS AND DISCUSSION

5.1 Outdoor climate

The meteorological data of HCMC from Tan Son Hoa weather station published by the Ministry of Construction in 2009 show that the maximum, minimum, and average temperature was 34.6°C, 26°C, and 29.2°C respectively over both April and May. Furthermore, the RH values ranged from 72% to 79%, and the average airspeed varied from 2.5 to 3.3m/s [9]; however, it was also noted that the city macroclimate was changing so more recent years were examined.

World Weather Online (WWO) predictions for HCMC in 2017 indicated changes with mean values of temperature, RH, and airspeed in those months being 34°C, 67%, and 3.8m/s respectively. Additionally, the air temperature peaked at 38°C in April. The total summer sun hours also increased to more than 300. The HCMC WWO climate predictions are relatively similar to the on-site measurements in terms of temperature and RH, but there is a significant divergence for air velocity measured in the field study and the recorded meteorological data. Although values of air velocity at a height of 10m are closer and more closely matched to the weather station, this is not the case for lower levels within urban areas.

Summarising data from 59 environmental measuring points around the city at levels under 10m shows that the average temperature was 32.6°C (SD 1.63); mean RH was 61% (SD 8.06) and air velocity was 0.32m/s (SD 0.19) (Table 2). Over summer, the outdoor temperature and airspeed reached a peak at nearly 38°C and 0.9m/s respectively. Furthermore, when comparing to official Ministry data for microclimates, the environmental values of actual measurements were higher than the threshold of the acceptable thermal zone in hot months (29.5°C) [12]. In short, the microclimatic conditions surrounding the dwellings of HCMC in summer are more likely to provide urban discomfort for residents because of hot air and still winds.

Table 2: The outdoor environment in summer over 59 cases

	N	Min.	Max.	Mean	Std. Dev.
Air temperature °C	59	29.5	37.8	32.6	1.63
Relative humidity RH	59	41	79	61	8.06
Air velocity m/s	59	0.07	0.9	0.32	0.19

5.2 Summer microclimatic conditions

The on-site measurements of the physical variables at 59 different locations across the city in summer 2017 show the variations of the urban environment at micro-scale of the residential blocks. The environment surrounding dwellings classified according to four groups of urban structures was evaluated using boxplot analysis of air temperature, RH, and air movement.

Air temperature

Figure 3 shows the hottest thermal condition in Type 3 dwellings, which was characterised by the highest median and maximum air temperature over summer. The hot environment around the buildings in this urban type may be the result of solar radiation being reflected by buildings and absorbed by asphalt roads. Due to the paucity of tree shading, the uncomfortable air temperature at the level of pedestrians is usually added to by the radiant and convective heat from high surface temperatures of unshaded roads. Reflected glare from the streets is also a problem for visual comfort.

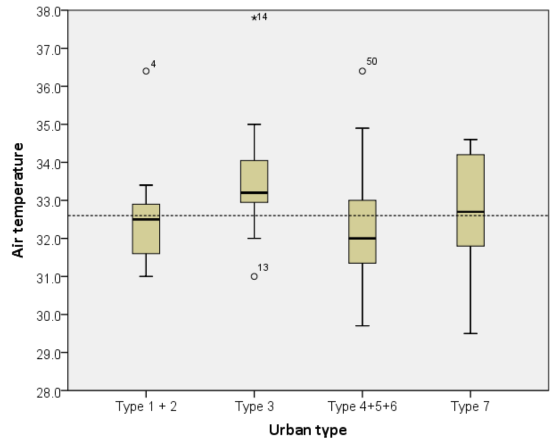

Figure 3: Distribution of air temperture

The average air temperature in Type 1&2 and Type 7 areas was similar and close to the average of 32.6°C. However, the variability of the thermal conditions during the day and between different locations in Type 1&2 was narrower at 2.5°C (31-33.5°C) compared to the variation of 5°C (29.5-34.5°C) in Type 7. In Type 4, 5 & 6, the mean of air temperature outdoors was the lowest of all seven urban patterns. Under the urban form depicted by the irregularity and high dwelling density in Group 3, overshadowing between buildings reduces the impact of solar heat, producing a cooler thermal condition in these types. However, the compact urban pattern may provide an obstruction for airflow and comfort convective cooling. In addition, the observations indicate a minimum temperature in Group 3 & 4 was the coolest at 29.5°C. The unplanned large green areas in Group 4 probably play a significant role in moderating the microclimatic conditions around residential neighbourhoods. Thus, the thermal environments here are more pleasant for the occupants.

Relative humidity

Relative humidity varied quite widely between 48% and 80% across the urban types during summer. Some details are shown in Figure 4. The hot air temperature caused the dry environment over summer in Group 2, while the air condition was more moisture in Group 1, 3, & 4. However, acceptable relative humidities as defined by TCVN 7438:2004, show that almost 100% and 75% of RH conditions surrounding Group 2 and Group 1,3,&4 respectively comply with the standard from 30% to 70%.

Data collated for the lowest density neighbourhoods (Type 1+2) and the highest density blocks (Type 4+5+6), the climate can be more humid; therefore the supplement of breezes is significance in improving the thermal comfort by dissipating moisture in the hot condition. In summer, the relative humidity in Group 1 and 3 peaked at 80% and 77% respectively.

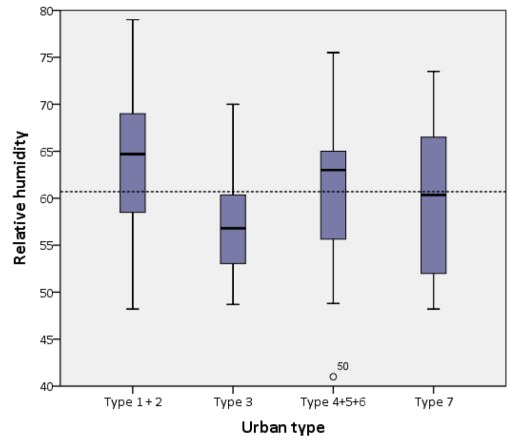

Figure 4: Distribution of relative humidity

Natural wind environment

Unlikely the meteorological data, the observations of the wind environment at the lower level within urban dwelling blocks show the majority of air velocities were weak, typically less than 0.3m/s over the summer period. The difference found between climatic data and actual measurements is significant for planning and design of dwellings.

From previous studies, the acceptability of natural wind range for occupants in the tropics was predicted as either 0.3-0.9m/s (i) [14] or 0.5-1m/s (ii) [15]. The histogram analysis of air movement in hot months concluded that the cooling effect provided by natural wind was not beneficial and insufficient over 53% or 75% of residential neighbourhoods surveyed in total corresponding to findings (i) or (ii).

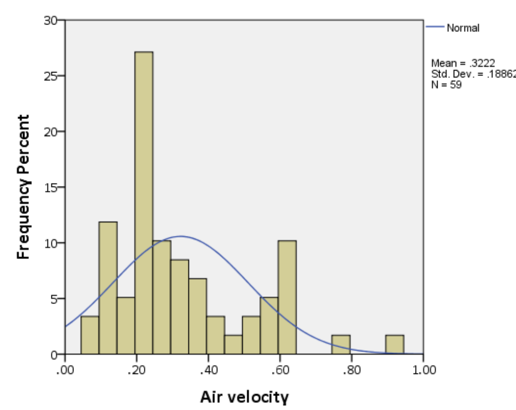

Figure 5: Distribution of air velocity measured in summer 2017

Airflow in the city ranged from 0.1-0.9m/s in summer months (Figure 5). However, the spatial structure of different urban types causes variations in the air movement environment. In observations of seven urban types, the condition of air flow in Type 1, 2, & 7 was the most comfortable because of certain beneficial urban characteristics, for example, the low population density, green sidewalks, regular road pattern, simple road system, and large open spaces around. Approximately 70% of airspeed values observed fell into the acceptable zone of 0.3-1m/s in these urban patterns. The maximum air velocity in Type 7 was recorded at 0.9m/s (Figure 6).

High-density construction and the irregular urban morphology may well explain the poor performance of wind flows in Types 4+5+6. 75% of airspeeds were lower than 0.3m/s, causing summer thermal discomfort in these types. In Type 3, the variability of wind speed was wide from 0.1 to 0.8m/s, and half the values were above 0.3m/s in the hot months.

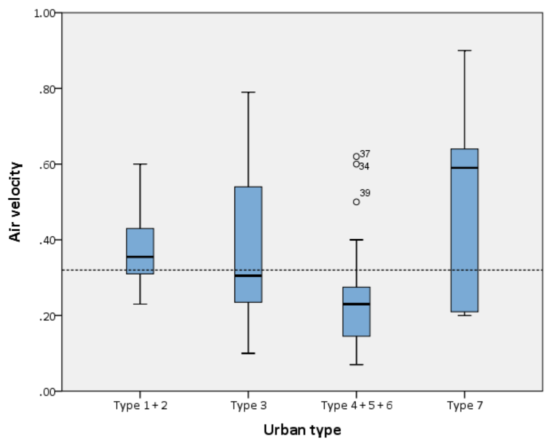

Figure 6: Distribution of air movement by urban types in 2017

5.3 Investigating the thermal environment of two samples of residential neighbourhoods

This section studies the microclimate of two dwelling blocks: Type 2 (sample 1) and Type 3 (sample 2) by using computational analysis. The urban morphology of the two samples is described in Figure 7 and there are variations of urban parameters between both samples. Firstly, for building form and coverage, in sample 1, the housing design complies with some archetypes; the building height is 4 stories, and the building density is medium. In sample 2, the design of 4-story houses is non-homogeneous and the construction coverage is much denser. Secondly, despite the same regular road pattern in both samples; the pattern is more compact in sample 2 of Type 3. In sample 1, more open spaces and green sidewalks/driveways are observed; while the narrow/medium streets without trees/pavements are the only empty spaces within the block.

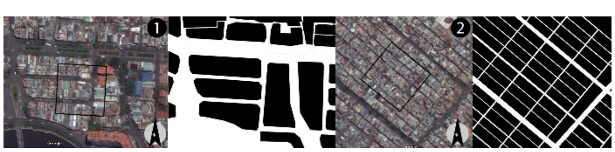

Figure 7: Urban pattern of two samples: Type 2 (1), Type 3 (2)

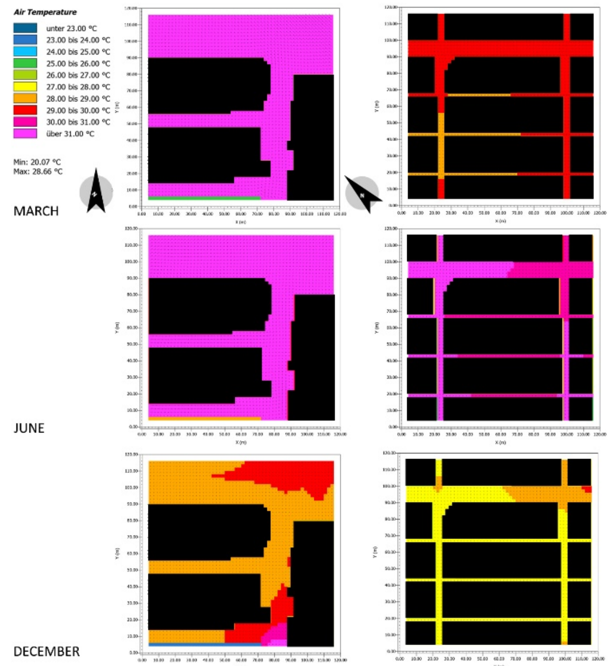

Figure 8: Distribution of air temperature of two studied urban types at 15:00 pm, on the 21st date (Vi Ho, 2017)

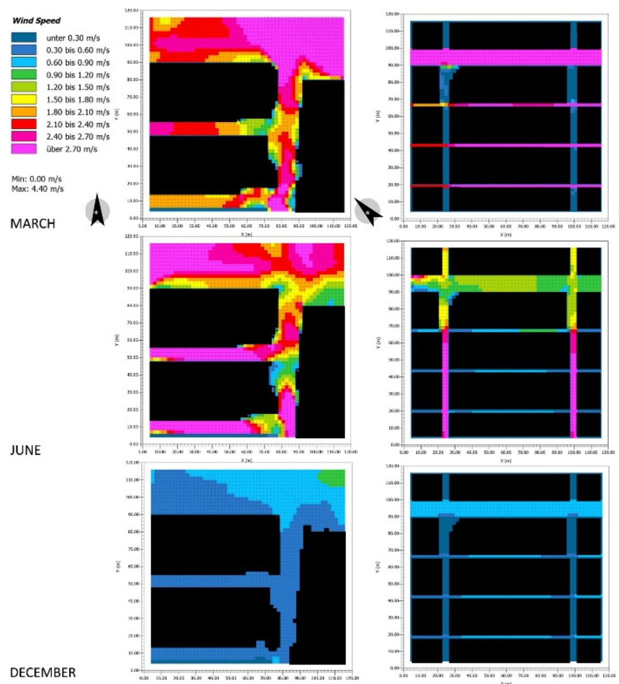

Figure 9: Air pattern of two studied urban types (Vi Ho, 2017)

Figure 8 shows the outdoor thermal performance of two samples at 15:00 pm, on the 21st date of March, June, and December. Despite the more green areas in sample 1, the wide asphalt roads contribute to an increase in temperature in the air around the dwellings. The thermal condition outdoors in this urban type is hotter than in sample 2 of Type 3 which gets the benefit of overshadowing between buildings. In December, the cooler climate of the city has caused the temperature to drop by 2-4°C in both samples compared to the hot ambient temperatures in summer. The hot condition in sample 1 can provide discomfort not only for the passengers outdoors but also for the occupants in naturally ventilated houses due to thermal exchange between internal and external climates. Moreover, in sample 2, the compact building pattern is effective in protection from solar heat and retaining coolness, but that is also a problem of weak air flows and poor daylighting.

Building density and narrow common spaces in sample 2 give a rise to the poor quality of wind flow through urban canyons within building groups over three studied months (Figure 9). In sample 2, the monthly change of wind direction has an impact on the variation of air flows. During March, wind typically flows horizontally in front of the building; however, vertical wind patterns along to building side is observed in June. Figure 9 shows the simulated results of air pattern are comfortable for the occupants in March and June in sample 1 of Type 2. The free open spaces combining vegetation can accommodate the air flows around the block with a wide air movement range of 0.6-2.7m/s. However, in December, the wind condition is still with an air velocity of under 0.3m/s in both samples, which may impact on occupants' thermal satisfaction.

6. CONCLUSION

The study confirms thermal discomfort in exterior climates in cities of the tropics such as HCMC. This arises from urban development and human activities and likely subsequent to affect indoor comfort and lead to higher levels of energy use.

The field measurements show the existence of heat islands in macro-neighbourhoods across the city. The unplanned and planned development of compact urban areas may result in warmer conditions and reduced natural wind flows. The outdoor environments were thermally uncomfortable due to observations of hot air temperature and the still air velocity across the majority of the city.

At the micro-scale of housing urban blocks, spatial planning factors have significant impacts on the environmental conditions around buildings. Variations in microclimate were found in the field studies and simulation under different urban morphologies. The deviation of physical values between urban types includes 0.5-1°C of air temperature, 3-7% of humidity, and 0.2-0.4m/s of wind speed in summer. The more comfortable environment was found in Type 1,2 & 7. The results of the study encourage practitioners to consider urban microclimate and to find the correlation between changes of outdoor climate and interior environment at the beginning of the design process. Further measurements carried out simultaneously in more and different urban areas of the city would facilitate even better analysis. In addition, comfort surveys for pedestrians would offer potential to correlate between climate and human sensations.

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REFERENCES

1. Tran, G. V., & Tran, D. B. (1998). *Cultural monography of Ho Chi Minh City - Volume 1: History.* Ho Chi Minh City: The Ho Chi Minh City Publishing House.

2. CPHSC. (2010). *The 2009 Vietnamese population and housing census: Major findings.* Hanoi: Central population and housing census steering committee.

3. Statistics Office. (2015). *Population and labour.* Ho Chi Minh City: Statistics Office of Ho Chi Minh City.

4. Tran, V. T., & Ha, B. D. (2010). Study of the impact of urban development on surface temperature using remote sensing in Ho Chi Minh City, Southern Vietnam. *Geo. Research*, 86-96.

5. Allegrini, J., Dorer, V., & Carmeliet, J. (2015). Influence of morphologies on the microclimate in urban neighbourhoods. *Journal of Wind Engineering*, 108-117.

6. Asfour, O. S. (2010). Prediction of wind environment in grouping patterns of housing blocks. *Energy and Buildings*, 2061–2069.

7. Rajagopalan, P., Lim, K. C., & Jamei, E. (2014). Urban heat island and wind flow characteristics of a tropical city. *Solar Energy*, 159-170.

8. Downes, N. K., & Storch, H. (2014). *The urban structure types of Ho Chi Minh City, Vietnam.* Brandenburg: Cottbus, Brandenburgishe Technische Universität, IKMZ.

9.IBST. (2009). *Vietnam Building Code: Natural physical & Climatic data for construction.* Hanoi: Ministry of Construction.

10.Storch, H., & Downes, N. (2011). The dynamics of urban change in times of climate change – The case of Ho Chi Minh. *REAL CORP 2011: CHANGE FOR STABILITY: Lifecycles of Cities and Regions* (pp. 977-984). Essen: CORP.

11.Thuc, T., Nguyen, T. V., Huynh, H. T., Mai, K. V., Nguyen, H. X., & Doan, P. H. (2016). *Climate change and sea level rise scenarios for Vietnam.* Hanoi: MoNRE.

12.MOC, M. (2004). *TCXDVN 306:2004 - Dwelling and public buildings - Parameters for microclimates in the room.* Hanoi: Ministry of Construction.

13.VSQI, (. (2005). *TCVN 7438:2004 - Ergonomics. moderate thermal environments. determination of the PMV and PPD indices and specification of the conditions for thermal comfort.* Hanoi: Ministry of Science and Technology.

14.Gong, N., Tham, K., Melikov , A., Wyon , D., Sekhar , S., & Cheong , K. (06 de 06 de 2006). The acceptable air velocity range for local air movement in the tropics. *HVAC&R Research*, pp. 1065-1074.

15.Szokolay, S. V. (1997). Thermal comfort in the warm-humid tropics. *ANZAScA'97 - Principles and Practice* (pp. 7-12). Brisbane: ANZAScA.